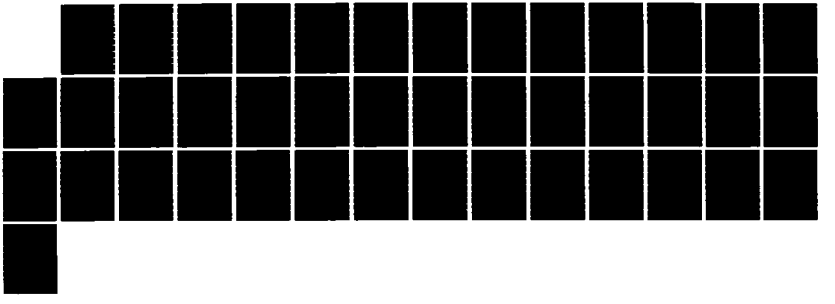
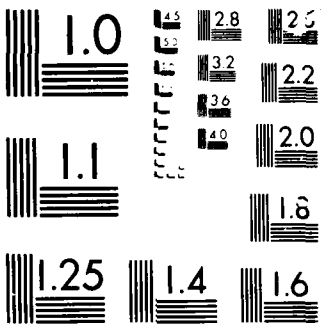
AD-A168 611 MASS SPECTROMETRIC INVESTIGATION OF THE THERMAL DECOMPOSITION OF SEVERAL..(U) SPACE SCIENCES INC MONROVIA CA M FARBER ET AL. FEB 86 N00014-80-C-0711 F/G 19/1 1/1 NL

UNCLASSIFIED





MICROCOPY CHART

(2)

SPACE SCIENCES, INC.

135 WEST MAPLE AVENUE • MONROVIA, CALIFORNIA 91016 • (818) 357-3879

MASS SPECTROMETRIC INVESTIGATION OF THE THERMAL DECOMPOSITION OF SEVERAL PROPELLANT AND EXPLOSIVE INGREDIENTS

FINAL REPORT

Contract N00014-80-C-0711

Department of the Navy
Office of Naval Research
Arlington, Virginia 22217

February 1986

Participants:
Milton Farber
S. P. Harris
R. D. Srivastava

This research was sponsored by the Office of Naval Research.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A168 677	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* Mass Spectrometric Investigation of the Thermal Decomposition of Several Propellant and Explosive Ingredients		5. TYPE OF REPORT & PERIOD COVERED Final 1 August 1980 - 31 Dec 1985
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Milton Farber, S. P. Harris and R. D. Srivastava		8. CONTRACT OR GRANT NUMBER(s) N00014-80-C-0711
9. PERFORMING ORGANIZATION NAME AND ADDRESS Space Sciences, Inc. 135 W. Maple Ave. Monrovia, CA 91016		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 092-554
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research (Code 432P) Arlington, Virginia 22217		12. REPORT DATE February 1986
		13. NUMBER OF PAGES 39
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)*
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited. Reproduction in whole or in part is permitted for any purpose by the United States Government.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

dehydrofefo (DHF)
3,3 bis [(methyl nitramino methyl)] oxetane (BMNAMO)
poly (3-nitratomethyl-3-methyl) oxetane (p-NMMO)
50/50 methyl nitramino methyl methyl oxetane/azido methyl methyl oxetane (50/50 MNAMMO/AMMO)

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Thermal decomposition kinetics, including an elucidation of the mechanisms, were determined for several energetic polymeric materials. These materials included poly (3-nitratomethyl-3-methyl) oxetane (p-NMMO), the copolymer, methyl nitramino methyl methyl oxetane/azido methyl methyl oxetane (50/50 MNAMMO/AMMO), and the monomer 3,3 bis[(methyl nitramino methyl)] oxetane (BMNAMO). Experiments were performed on both stabilized and unstabilized dehydrofefo (DHF) to determine its decomposition and evaporation at 132 F.

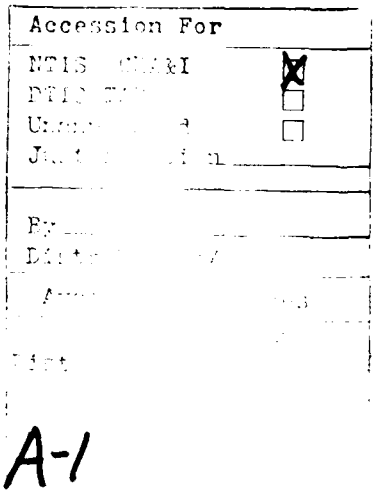
DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

19. Key Words, continued...

Thermal decomposition
Mass spectrometry
Monomers
Polymers
Copolymers
Activation Energies



This report presents a discussion of the experimental results for several monomers and polymers obtained from thermal decomposition studies during the last twelve months of the contract period. A summary of work accomplished during the first four years of the contract is also presented.

I. THERMAL DECOMPOSITION STUDIES DURING CURRENT YEAR

Thermal decomposition kinetics, including an elucidation of the mechanisms, were determined for several energetic polymeric materials. These materials included poly(3-nitratomethyl-3-methyl) oxetane (p-NMMO), the copolymer, methyl nitramino methyl methyl oxetane/azido methyl methyl oxetane (50/50 MNAMMO/AMMO), and the monomer [3,3 bis(methyl nitramino methyl)] oxetane (BMNAMO). Samples of these materials were supplied by Dr. G. E. Manser. Experiments were performed on both stabilized and unstabilized dehydrofefo (DHF) to determine its decomposition and evaporation at 132 F. These samples were furnished by Dr. R. Reed.

The experiments were performed employing this laboratory's dual vacuum chamber furnace and mass spectrometer system.[1,2] The samples were contained in an alumina effusion cell 25 mm long, with an inside diameter of 6.8 mm and having an elongated orifice of 0.75 mm in diameter and 5.5 mm in length for beam collimation. Thus the products resulting from sublimation or evaporation and decomposition entering the beam were studied without further reaction. Gas products within the effusion cell could react with the condensed phase as well as the cell walls prior to leaving the cell and entering the high vacuum of the mass spectrometer ($\sim 10^{-7}$ mm Hg) for ion identification.

A. Monomers

1. Dehydrofefo (DHF)

Explosives containing DHF have been found to lose weight when stored at 132 F (56 C). Therefore, an investigation was undertaken at this temperature to determine whether the weight loss was due to DHF evaporation, thermal decomposition, or a combination of both.

Samples of DHF and DHF stabilized with approximately 3% MNA were heated to 132 F (56 C) and their vapor products examined mass spectrometrically. Both samples produced similar vapor species. Figure 1

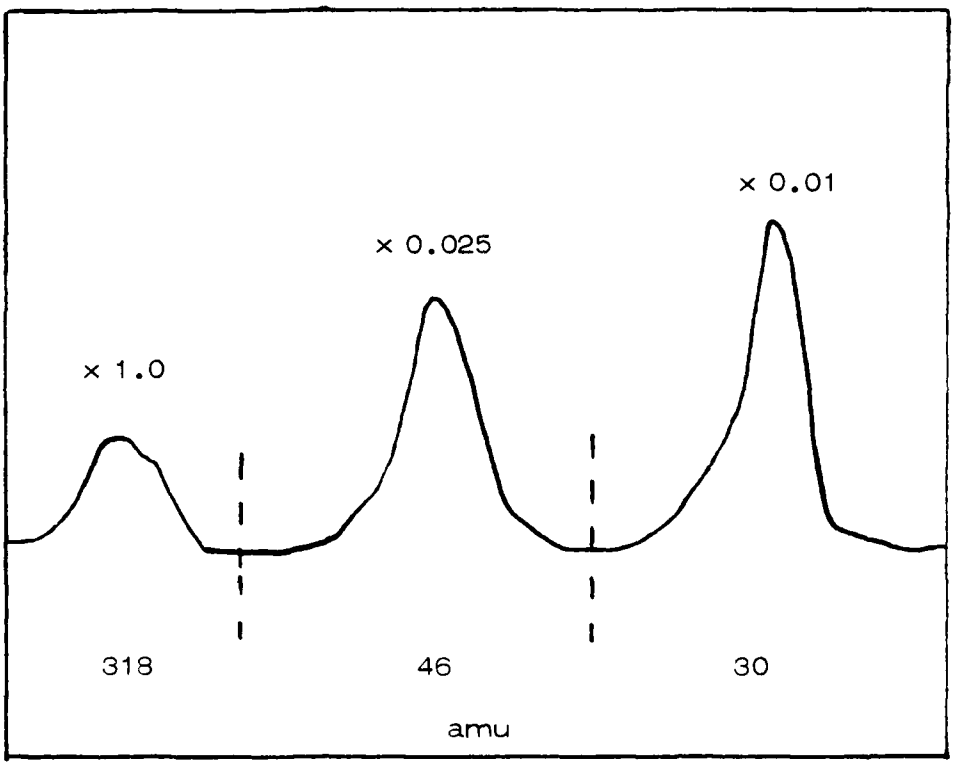
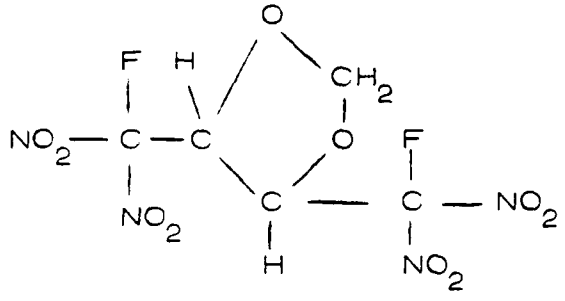
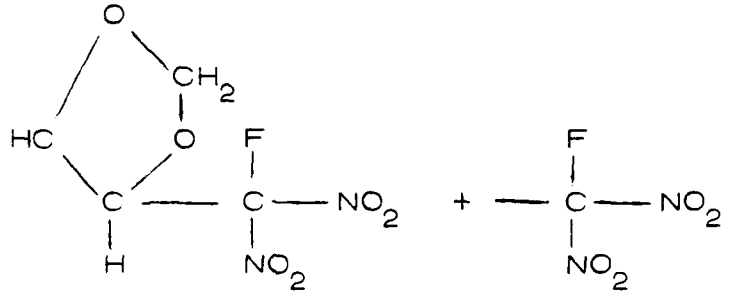


Fig. 1. Intensities due to DHF decomposition and evaporation at 132 F

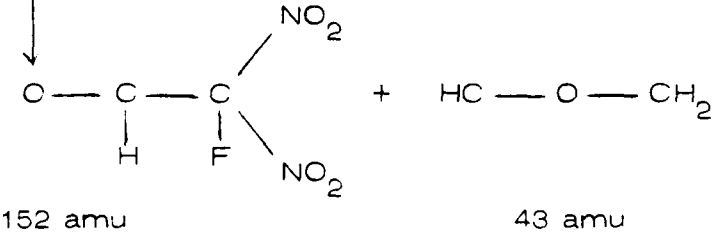
shows decomposition peaks at 132 F. As can be seen, less than 10 percent DHF was observed at 318 amu. Decomposition of the stabilized and unstabilized samples was nearly identical, both producing two large molecular fragments at 123 and 152 amu (Fig. 2). The ratio of 123/152 is 5.7 for DHF, and 5.0 for DHF stabilized with MNA. Peaks at 195, 152, 136 and 123 amu were observed for the two samples, corresponding to the fragments:



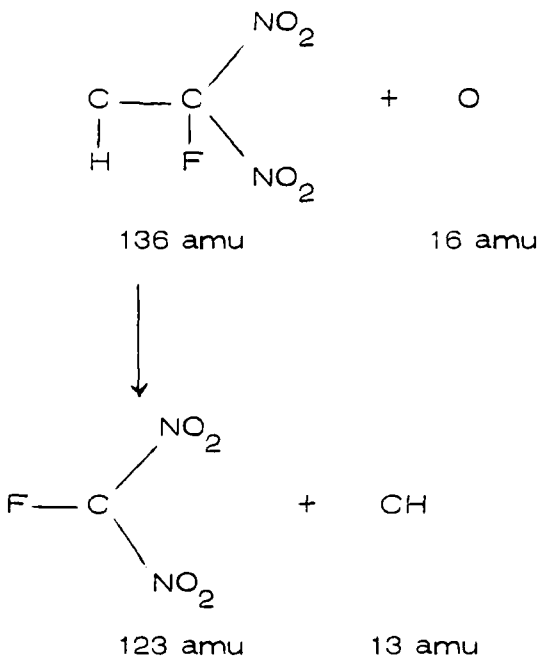
318 amu



195 amu



152 amu 43 amu



An evaporation energy of approximately 165 kJ mol^{-1} (40 kcal/mol) was obtained from a decomposition study in the temperature range 30 - 60 C (86 - 140 F).

2. 3,3 bis [(methyl nitramino methyl)] oxetane (BMNAMO)

Energetic nitramino group materials are continually being prepared and investigated. Previous thermal decomposition studies involving both the methyl nitramino methyl methyl oxetane monomer and the homopolymer were reported in our Annual Report dated September 1984. The bis compound, having two nitramino groups, would appear to be more energetic and therefore warrants investigation as a possible propellant or explosive ingredient. BMNAMO is stable to approximately 120 C with decomposition commencing above this temperature. At 150 C prominent decomposition fragment peaks are observed (Fig. 3.a. and 3.b.). Figure 3.a. depicts the mass spectra in the 90-190 amu range at 120 C; figure 3.b. is the spectra in the same amu range at 150 C. A mass spectrum of the decomposition products in the 50 - 115 amu range at 150 C is shown in Fig. 4. Figure 5 is a composite of the mass spectra in the 60 - 90 amu range. From these spectra a scheme for the decomposition mechanism is proposed. The peaks at 145 and 89 amu suggest a decomposition path as the breaking of the central oxetane carbon to the nitroamino appendage as

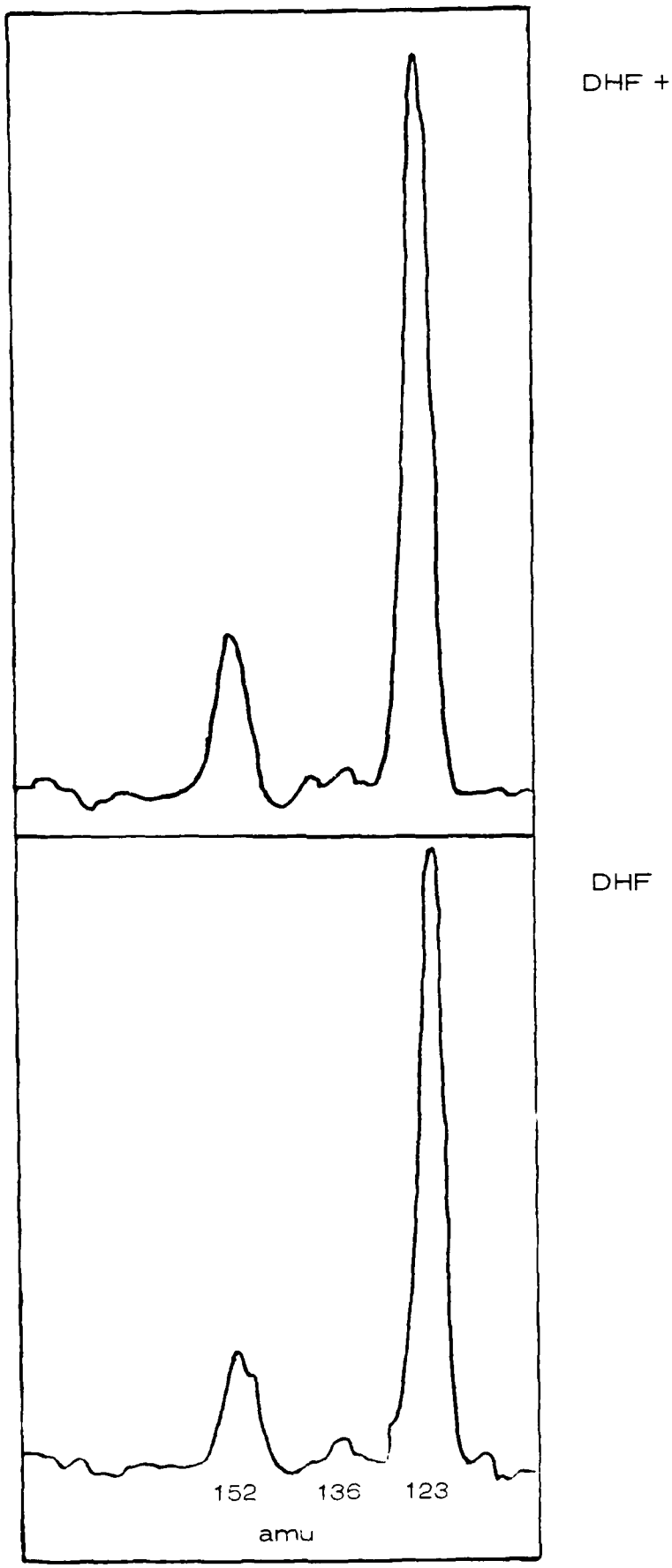


Fig. 2. Mass spectra comparison of pure DHF and DHF stabilized with 3% MNA at 60 C

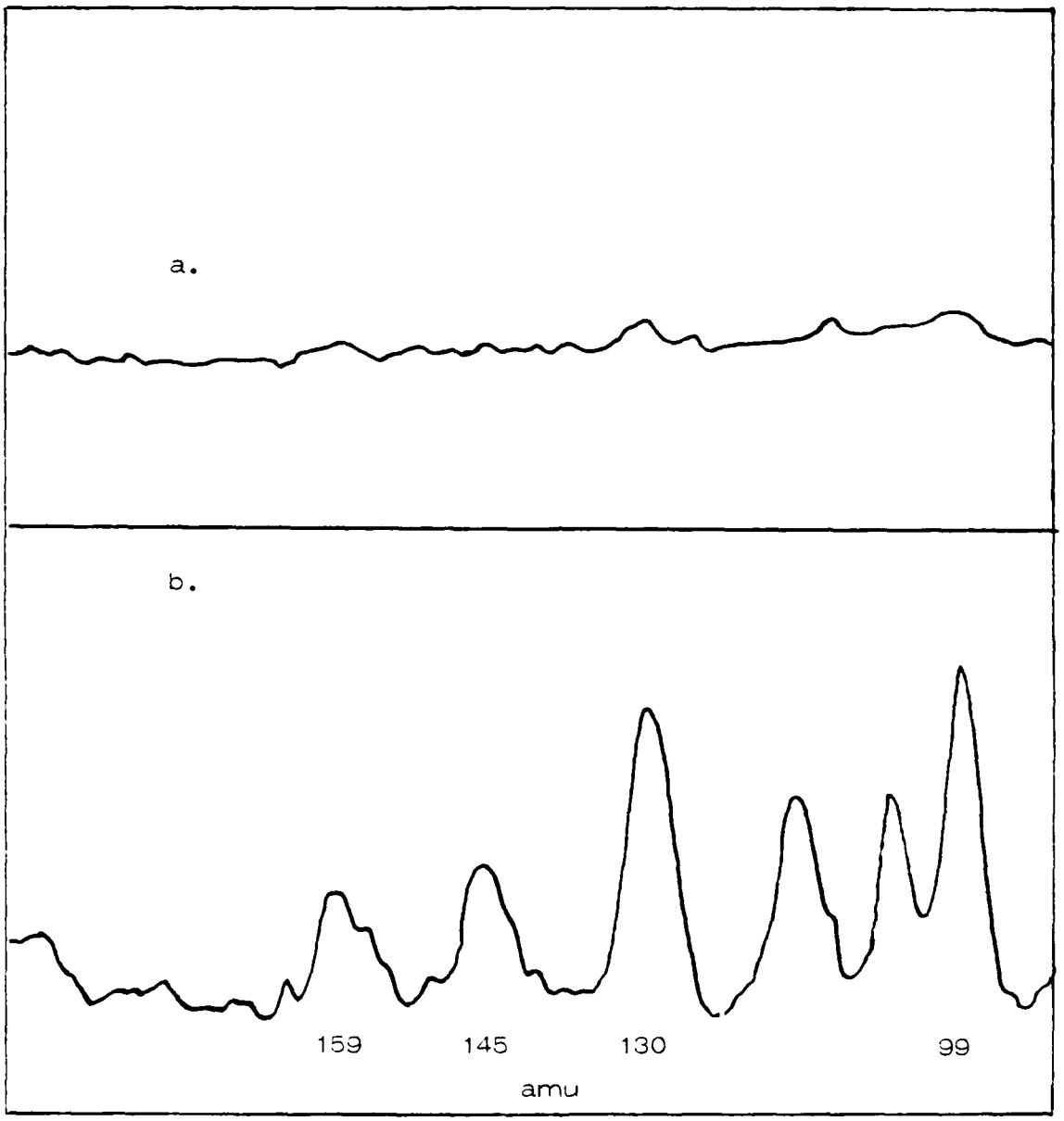


Fig. 3.a. Mass spectra in the amu range 90 - 190 for BMNAMO at 120 C

Fig. 3.b. Mass spectra in the amu range 90 - 190 for BMNAMO at 150 C showing considerable molecular decomposition

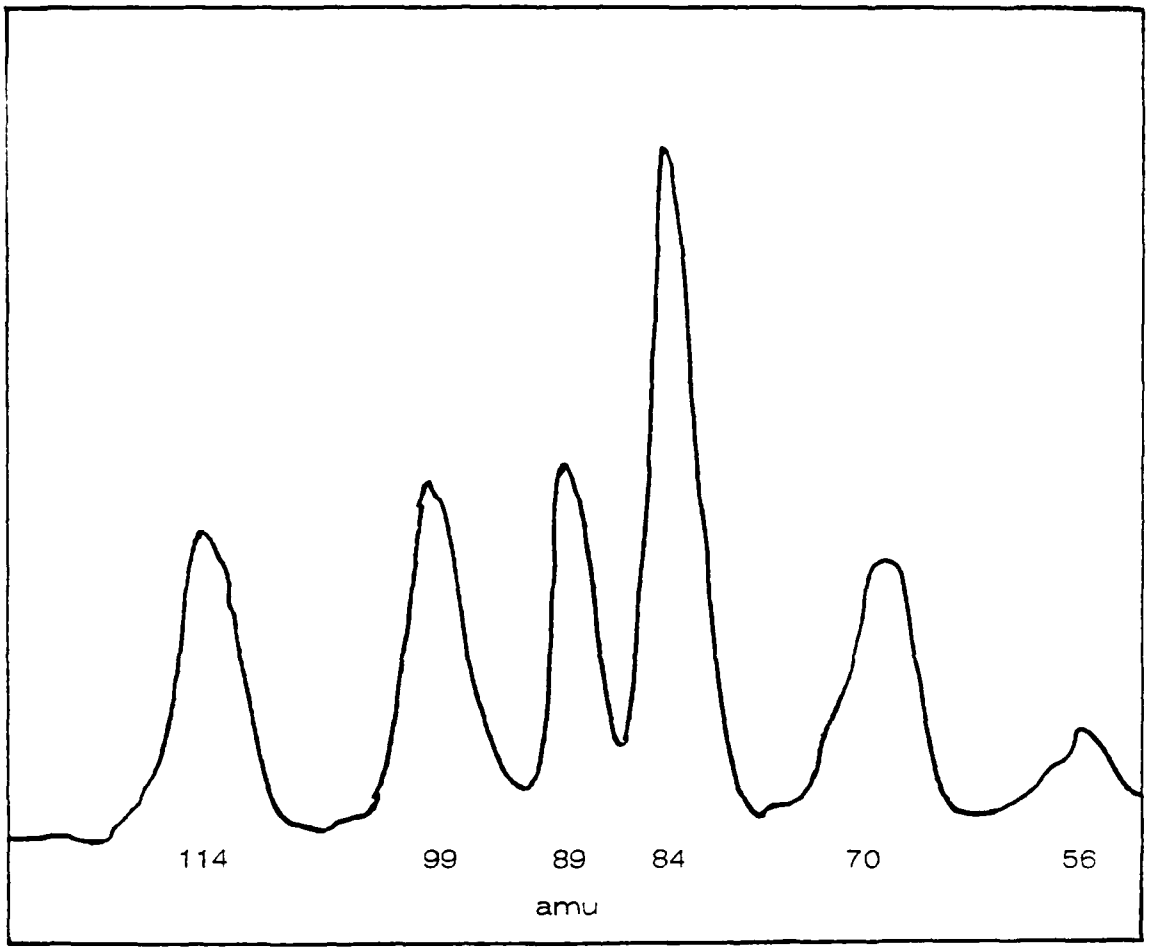


Fig. 4. Mass spectra in the 50 - 115 amu range for the decomposition products of BMNAMO at 150 C

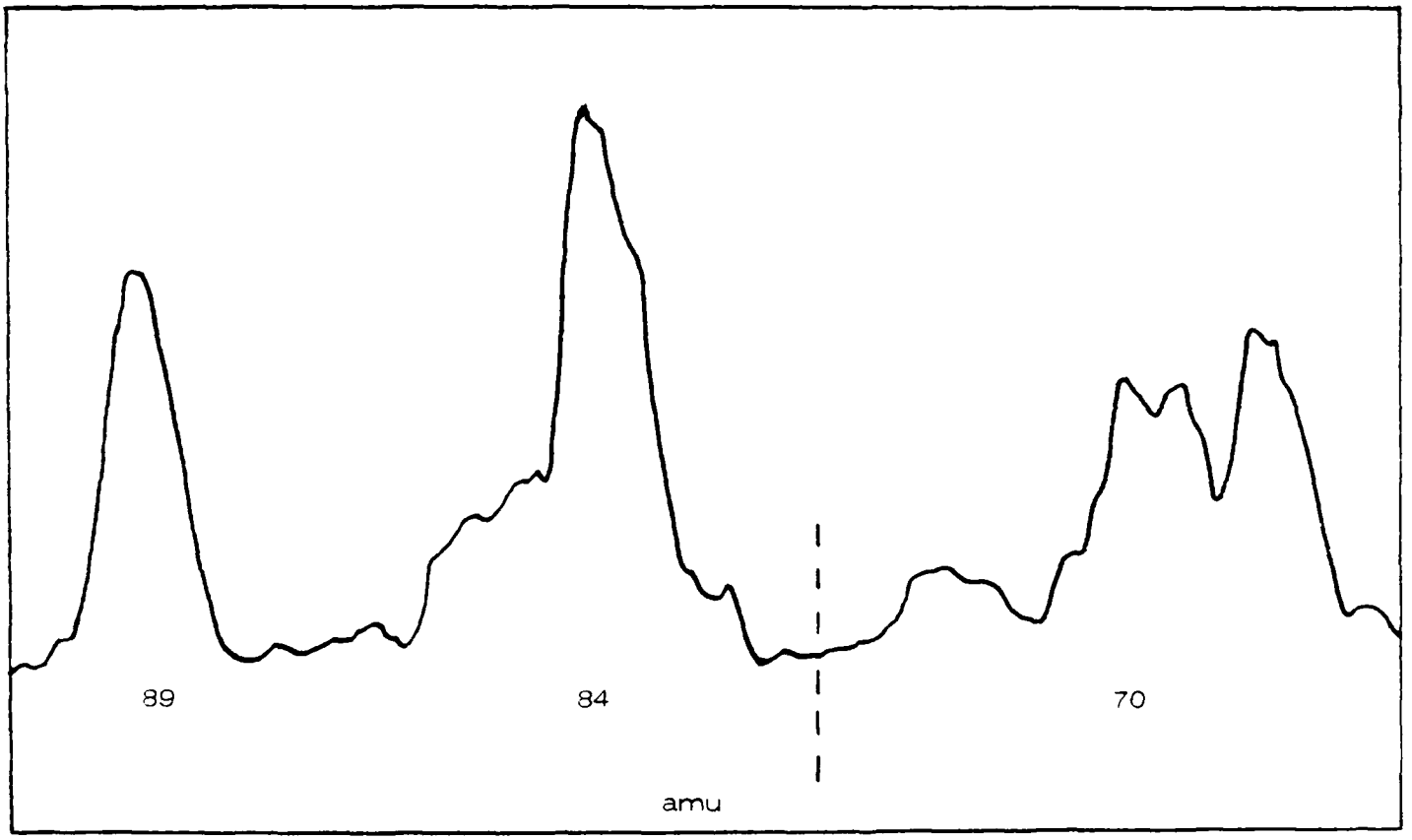
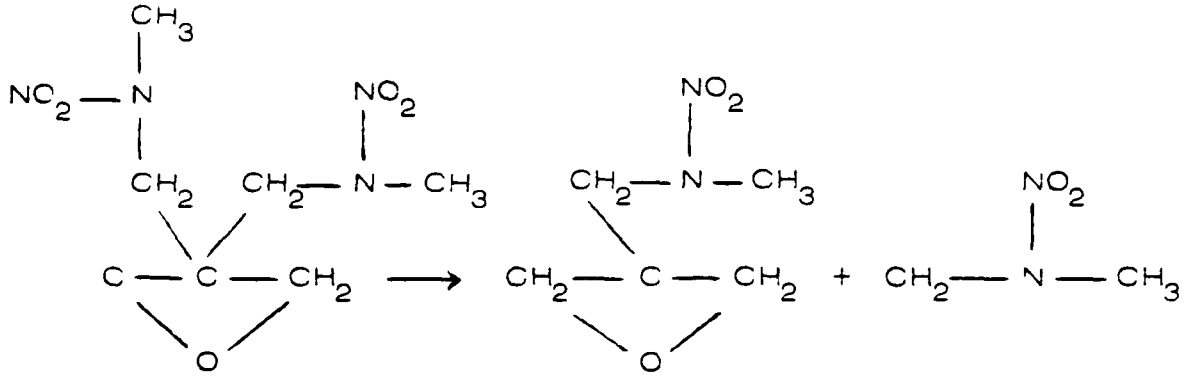
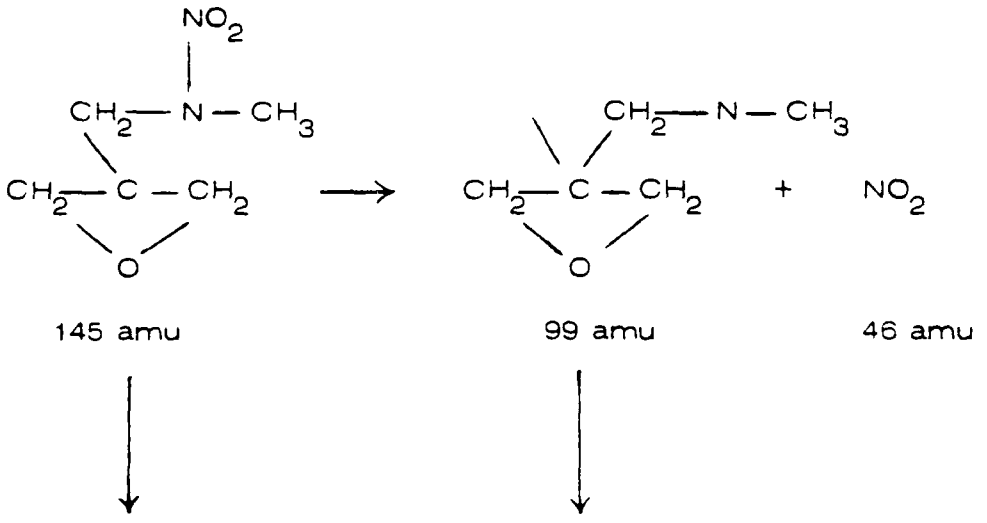


Fig. 5. Mass spectra in the 60 - 90 amu range for the decomposition products of BMNAMO at 150 C (spectra are continuous only within the dashed line)

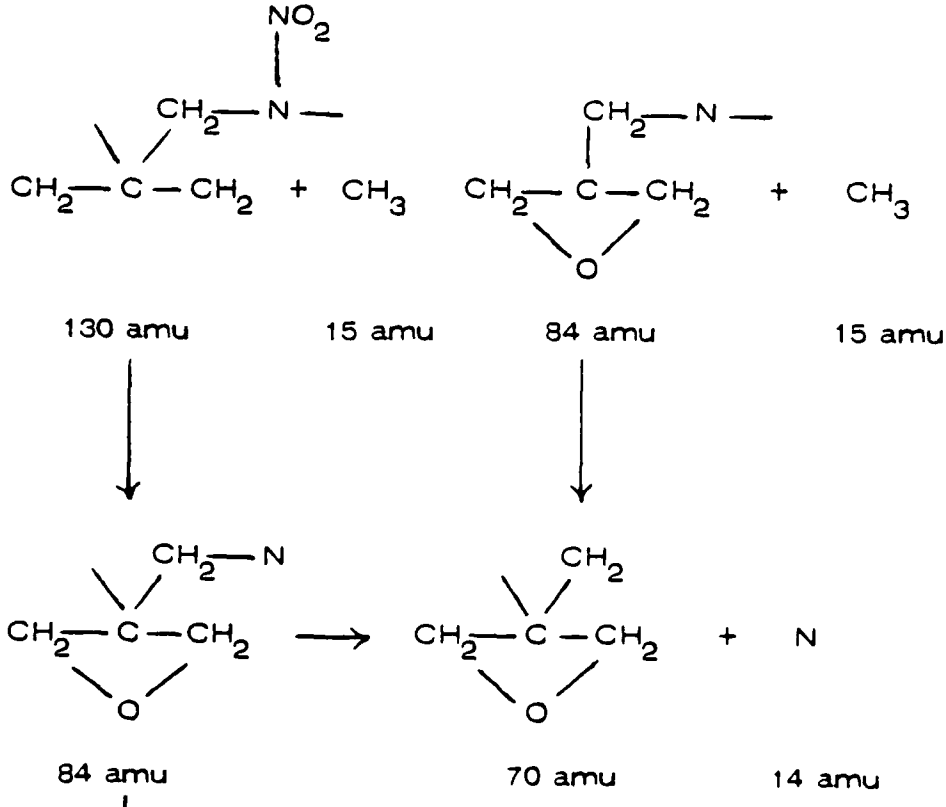


234 amu 145 amu 89 amu

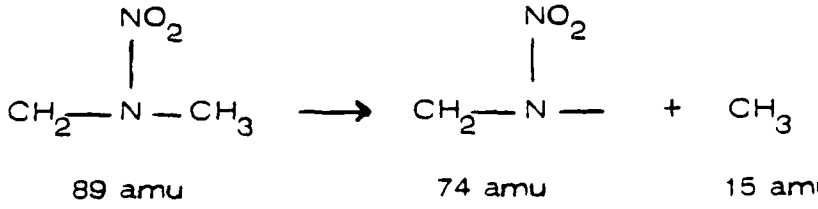
There is also an indication of C–N bond cleavage, with the observation of a small concentration of a 159 amu peak. Reactions continue within the effusion cell, with further decomposition of the larger fragments yielding the observed ion intensity peaks of 130, 99, 84, 75, 74, 70, 56, 46, 28 and 15 amu. Possible molecular compositions of these structures are



145 amu 99 amu 46 amu



The appendage, $CH_2—N(NO_2)—CH_3$, also decomposes as

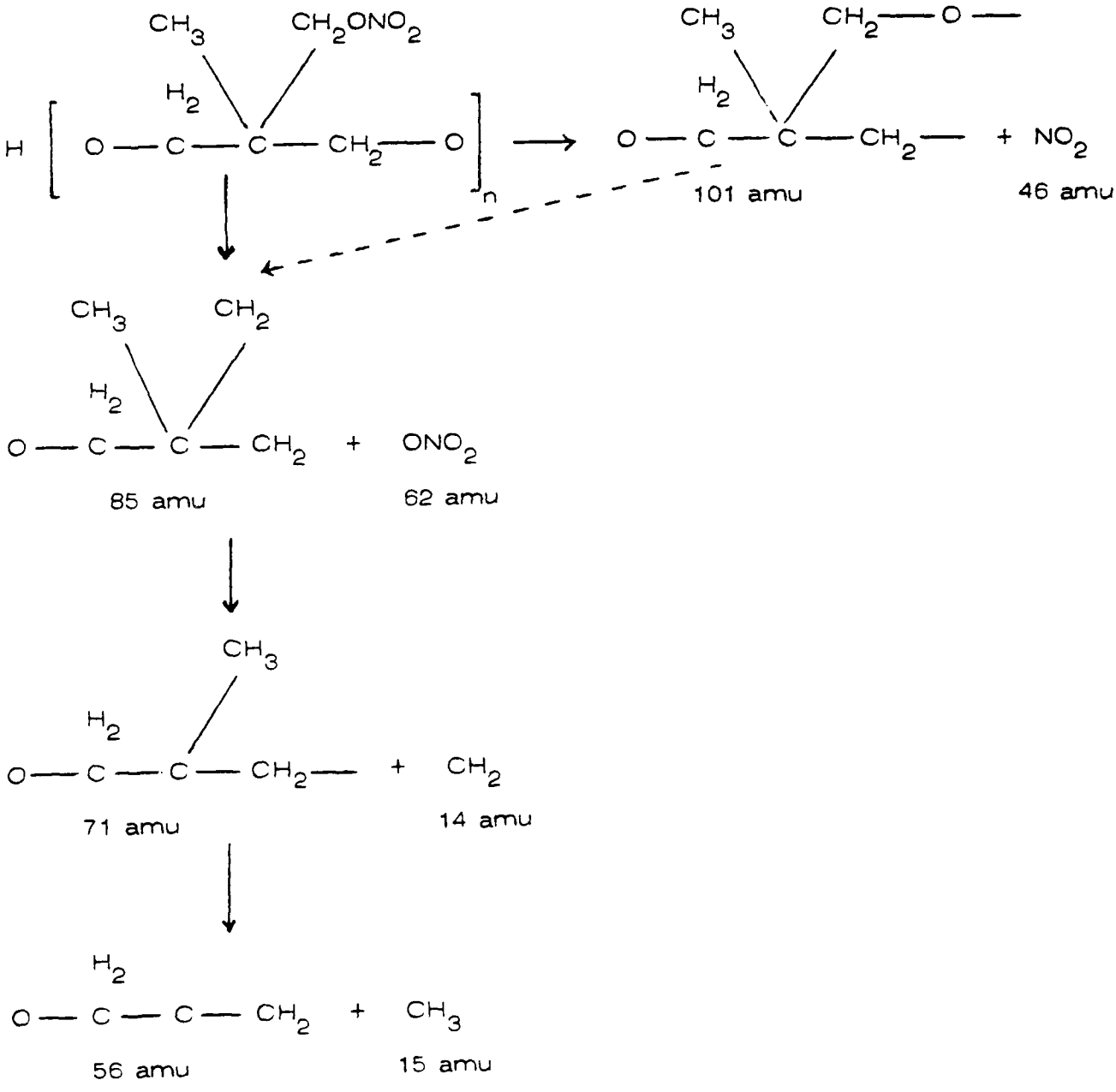


In addition, the usual small amu radicals and molecules observed in previous oxetane decomposition were seen.

B. Polymers

1. Poly (3-nitratomethyl-3-methyl) oxetane (p-NMMO)

A promising polymeric material appears to be poly (3-nitratomethyl-3-methyl) oxetane (p-NMMO). This material begins to decompose at approximately 100 C. Figure 6 shows the decomposition products in the amu range 14 - 105 at 150 C, where decomposition of the oxetane backbone is occurring. From these spectra the proposed decomposition methanism is:



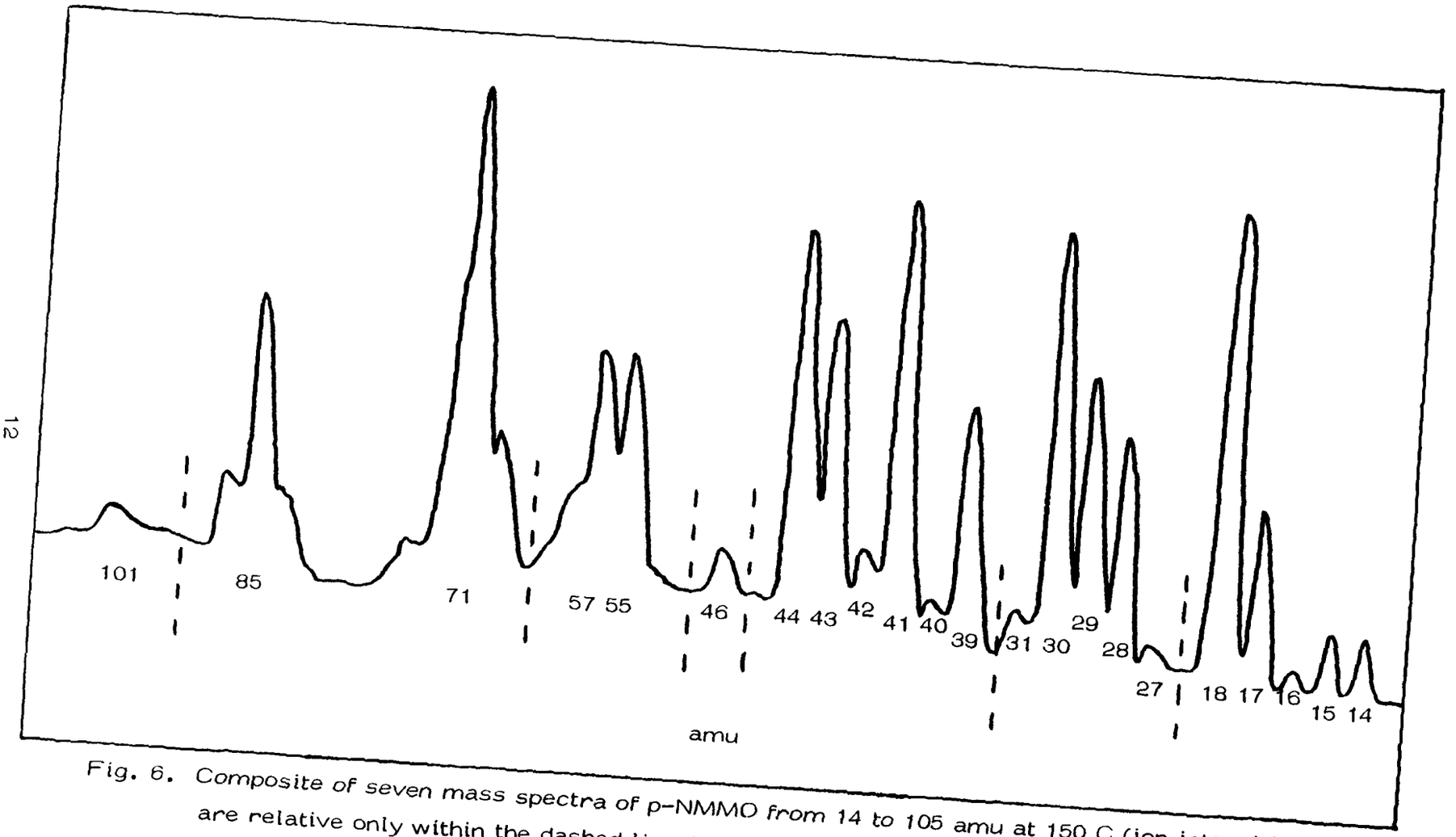


Fig. 6. Composite of seven mass spectra of p-NMMO from 14 to 105 amu at 150 C (ion intensities are relative only within the dashed lines)

A relatively small concentration of a product at 101 amu suggests a decomposition path with the release of NO_2 occurring from the rupture of the nitrate bond, O–NO_2. The low amu decomposition products are CH_2O at 30 amu, CHO at 29 amu, and CO at 28 amu. The prominent peaks at 14, 15 and 18 amu indicate CH_2, CH_3 and H_2O. The temperature dependence of the decomposition rate from 100 to 135 C is shown in Fig. 7. A 50-fold increase in relative ion intensities of NO_2 over this temperature range leads to an activation energy of 163 kJ mol^{-1} (39 kcal/mol).

Other laboratories are also investigating the thermal decomposition kinetics of p-NMMO.[5,6] DSC studies by Manser appear to suggest that nitrate ester decomposition is more thermally stable than the backbone cleavage. However, he reports that DSC kinetics employing the Ozawa multiple heat rate method do not support this observation. The FTIR investigation of Brill, made at higher temperatures (500 - 950 k) than those conducted at our laboratory (under 500 K), also indicates that the nitrate ester backbone decomposition is the primary mechanism, based on a high concentration of formaldehyde (65%) at 950 K. The method employed at our laboratory involves fast-time sampling (on the order of 100 micro-seconds or less) of the products mass spectrometrically. The initial gas products of the decomposition are thus allowed to enter the high vacuum of the mass spectrometer where they can be definitively identified. The method has proved successful in determining the thermal decomposition mechanism for HMX[3] and RDX.[4]

Since the results concerning the primary mechanism for p-NMMO (whether backbone cleavage or nitrate ester decomposition) are somewhat in disagreement, the three laboratories mentioned are planning to continue their efforts towards successfully elucidating the kinetics for this polymer.

2. Copolymer, 50/50 methyl nitramino methyl methyl oxetane/ azido methyl methyl oxetane (50/50 MNAMMO/AMMO)

The initial decomposition of the copolymer is quite similar to that of the individual homopolymers MNAMMO and AMMO. Decomposition gases evolving from the copolymer were observed as mass spectra at temperatures as low as 80 C. These gaseous products are from the

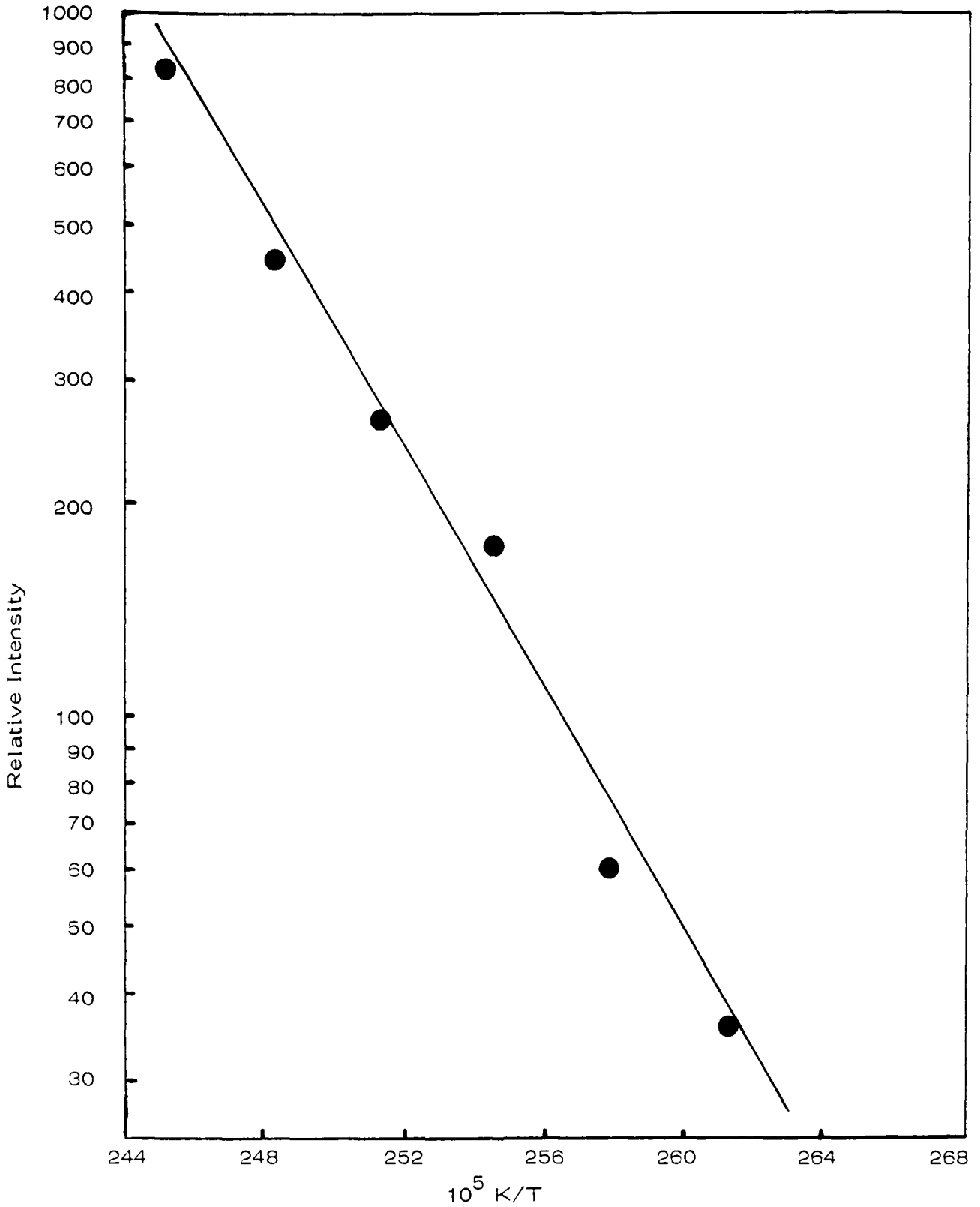
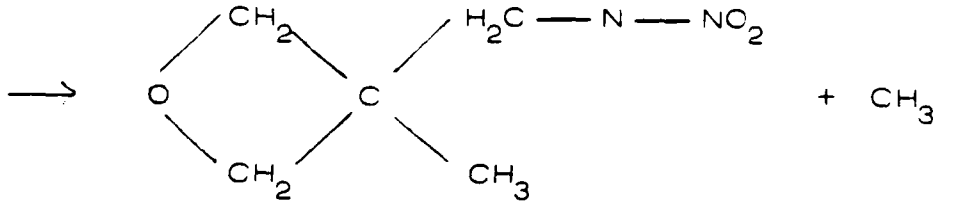
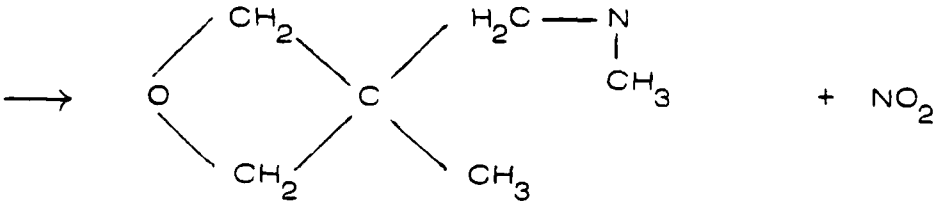


Fig. 7. Rate of decomposition of p-NMMO in the temperature range 100 to 135 C leading to an E_a of 163 kJ mol^{-1} (39 kcal/mole)

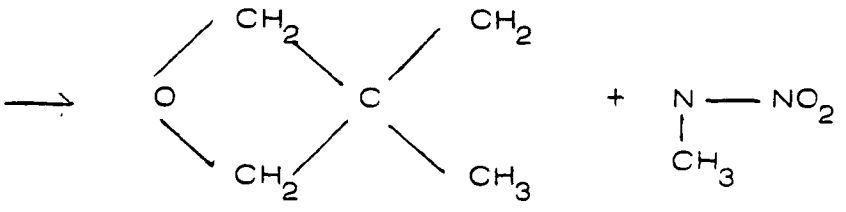
nitramine and agree with the decomposition peaks previously observed for the homopolymer. Figures 8.a. and 8.b. are comparison mass spectra and show the major ion intensities 85, 99, 114, 145, and 160 amu for the nitramine decomposition products at 120 C for both the copolymer (a.) and the homopolymer (b.). As can be seen, the relative intensities as well as the peaks are nearly identical for the homopolymer and the copolymer. This is substantial supporting evidence that the copolymer decomposes initially as separate homopolymers. The concentration of the nitramine fragment $CH_2\overset{CH_3}{\underset{|}{N}}-NO_2$ at amu 89 is quite temperature-dependent, as seen in Fig. 9. This figure shows the nitramine fragment increasing in intensity from its initial appearance at 70 C to a maximum at about 100 C, before its concentration commences to decrease. At 150 C a strong broad peak (81 - 83 amu) representing the oxetane backbone is observed. The mechanism for the nitramine polymer decomposition is the elimination of the entire nitramine arm or parts of the arm:



145 amu 15 amu



114 amu 46 amu



85 amu 75 amu

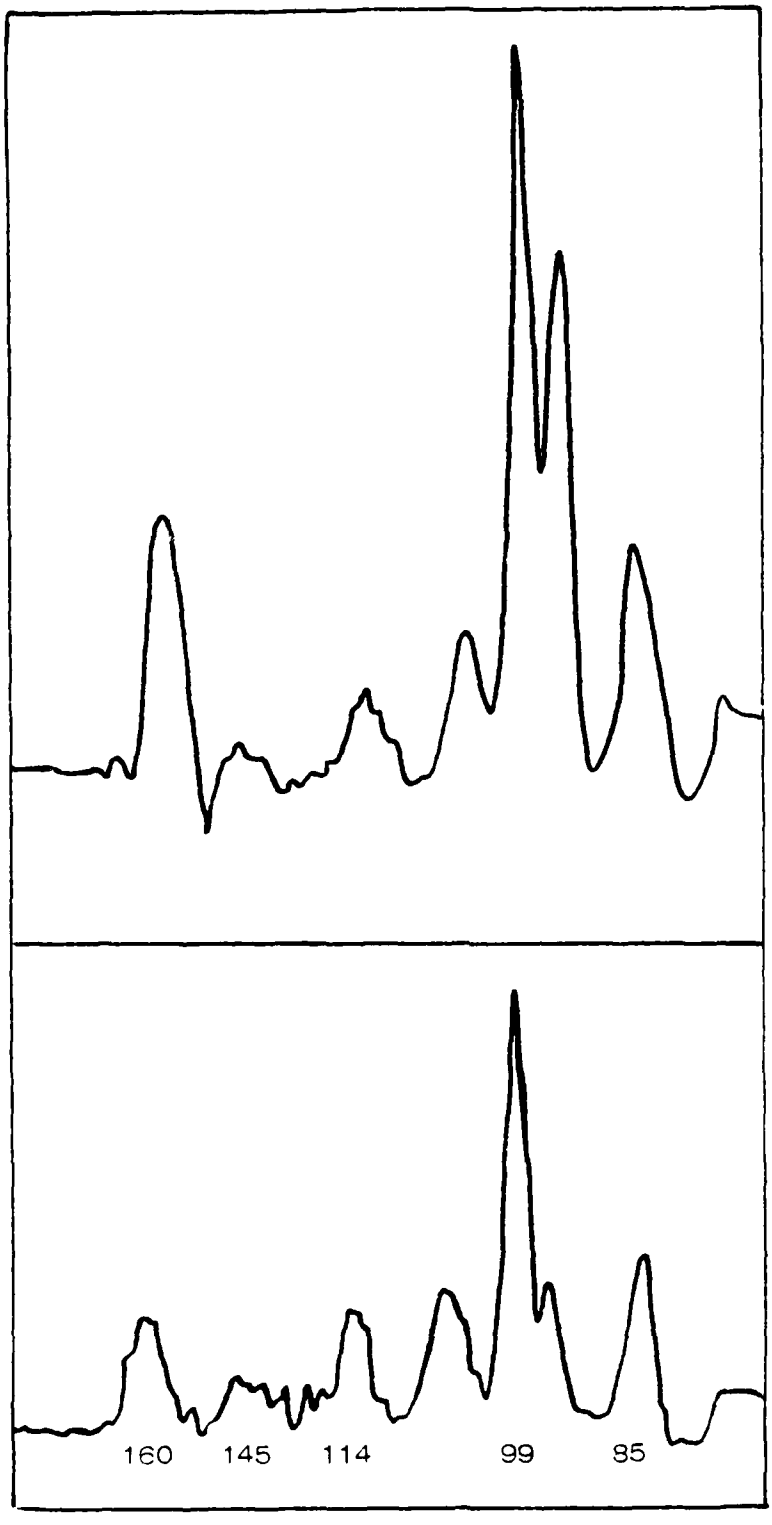


Fig. 8. Comparison of the thermal decomposition of 50/50 MNAMMO/AMMO (a) and of homopolymer p-MNAMMO (b) at 120 C. The relative intensities of the amu peaks in the 80 - 160 amu range indicate almost identical decomposition mechanisms for the copolymer and the homopolymer.

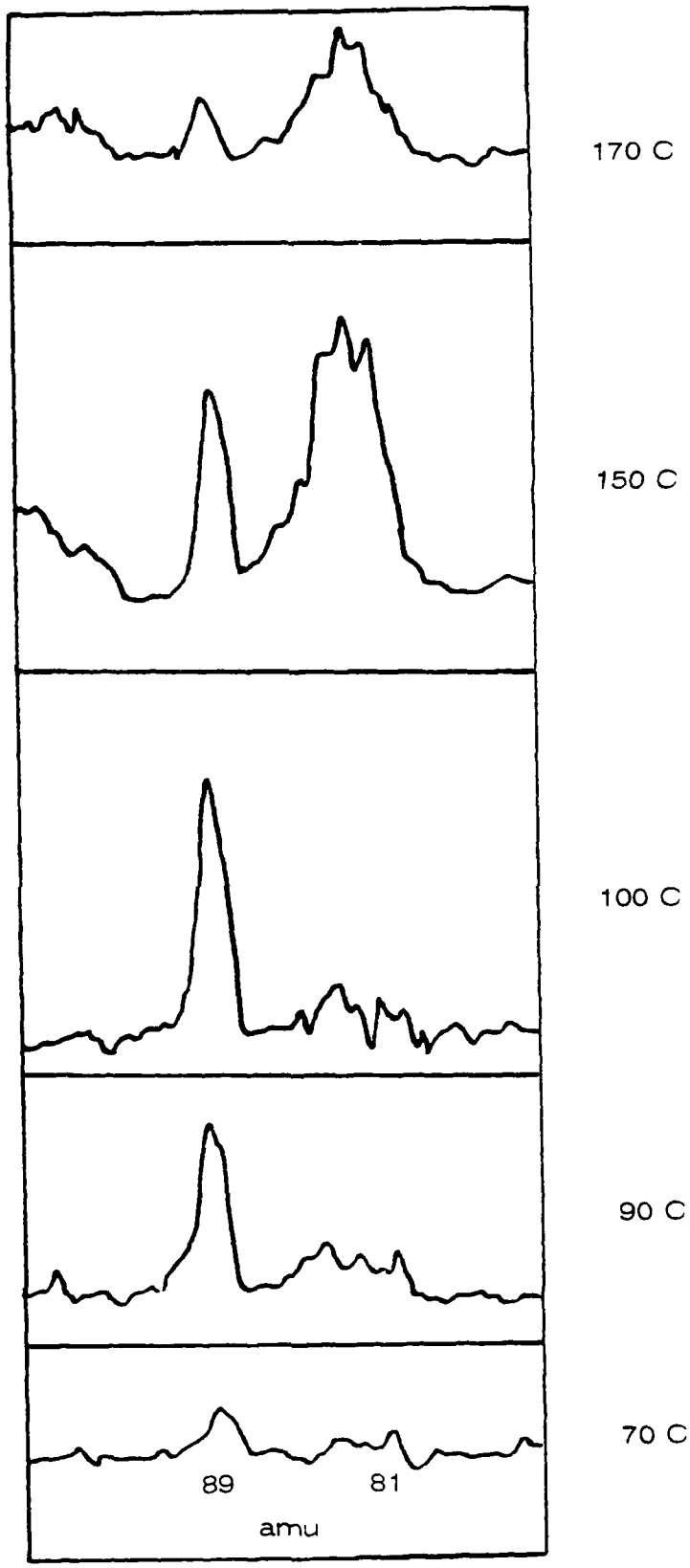
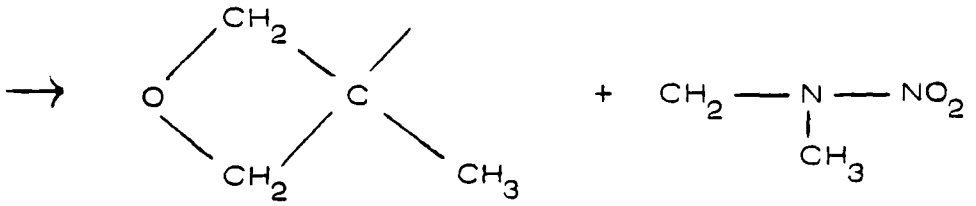


Fig. 9. Decomposition of 50/50 MNAMMO/AMMO as a function of temperature. The 89 amu peak represents the nitramino group whereas the 81 amu peak represents the oxetane backbone from AMMO decomposition.



71 amu 89 amu

Figure 10 shows the high temperature (over 150 C) decomposition of the copolymer in the amu range 14 - 45. The spectrum of the backbone decomposition of the copolymer provides supporting evidence that once initial decomposition takes place (i.e., the nitramine arm of MNAMMO and the N_2 release of AMMO), the remaining condensed phase decomposes differently than either backbone of the two copolymers. This can be seen from an examination of the mass spectra in Figs. 10, 11 and 12. Figure 11 depicts the mass spectra in the amu range 14 - 45 for both the homopolymer MNAMMO (a.) and the homopolymer AMMO (b.). The backbone decomposition of the copolymer has individual peaks (Fig. 10) found in both homopolymers, whereas the homopolymer decomposition spectra, Fig. 11.a. and 11.b., are not identical. This can be seen clearly from Fig. 12.a. and 12.b. Figure 12.a. is the spectrum in the 14 - 18 amu range for the copolymer, while Fig. 12.b. shows the peaks in the same amu range for homo AMMO. Of interest is the methyl radical, CH_3, at amu 15, of considerably greater concentration in the copolymer backbone decomposition than that of the homo AMMO. Also, it can be seen that the relative ratios of OH/H_2O concentrations are reversed.

III. WORK ACCOMPLISHED DURING PREVIOUS CONTRACT PERIODS

Thermal decomposition kinetics of energetic and non-energetic monomers and polymers were reported in the Annual Summary Reports of 1981 through 1984, as well as in open literature publications.

Brief summaries of these annual studies are presented below.

A. Annual Summary Report - September 1981

The kinetics of thermal decomposition were determined for poly 3,3 bis (azido methyl) oxetane (BAMO), glycidyl azide polymer (GAP),

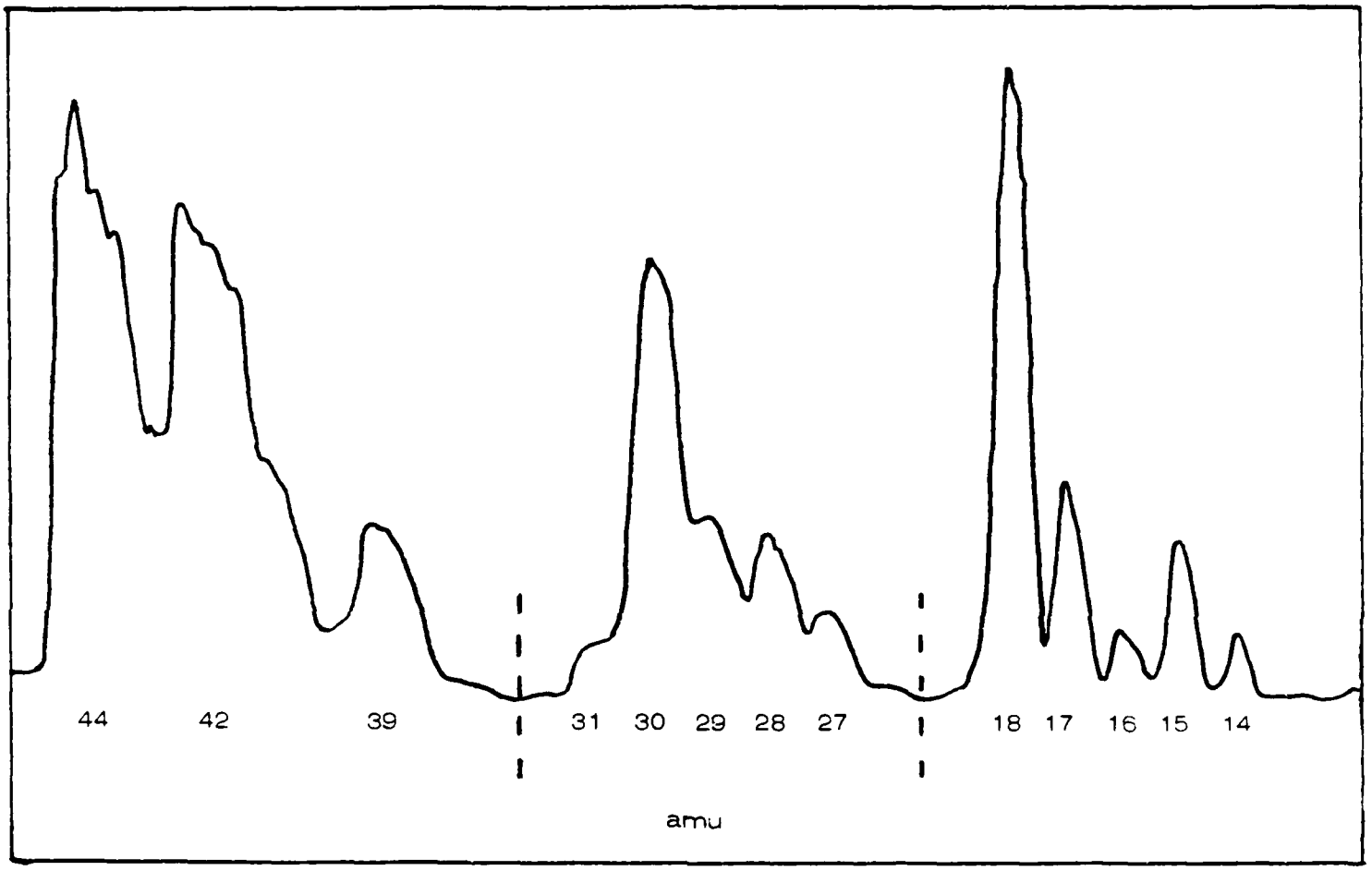


Fig. 10. High temperature thermal decomposition of 50/50 MNAMMO/AMMO at 160 C. The relative intensities are continuous only within the dashed lines.

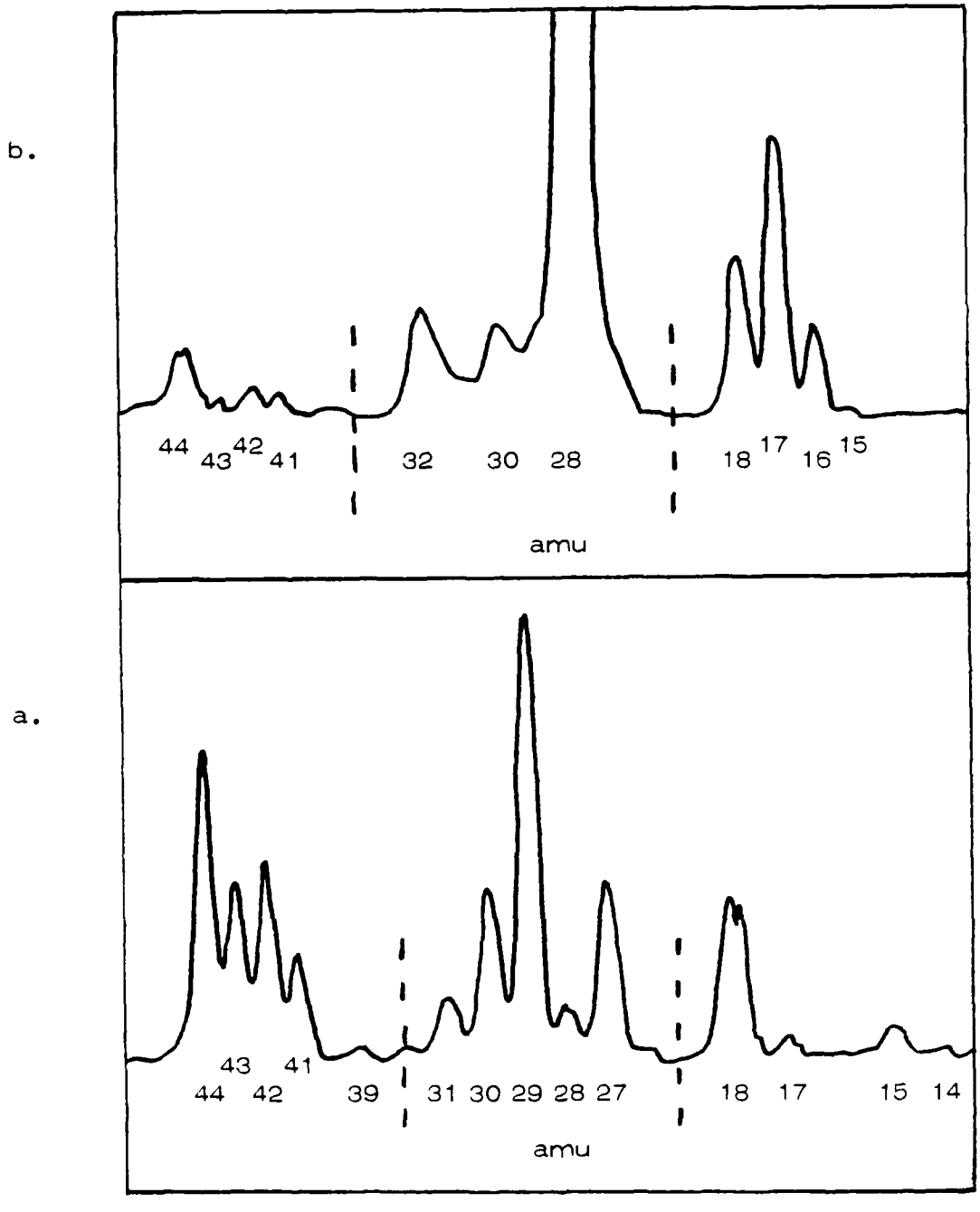


Fig. 11. High temperature thermal decomposition mass spectra of MNAMMO (a) and AMMO (b) in the 14 – 45 amu range (> 150 C)

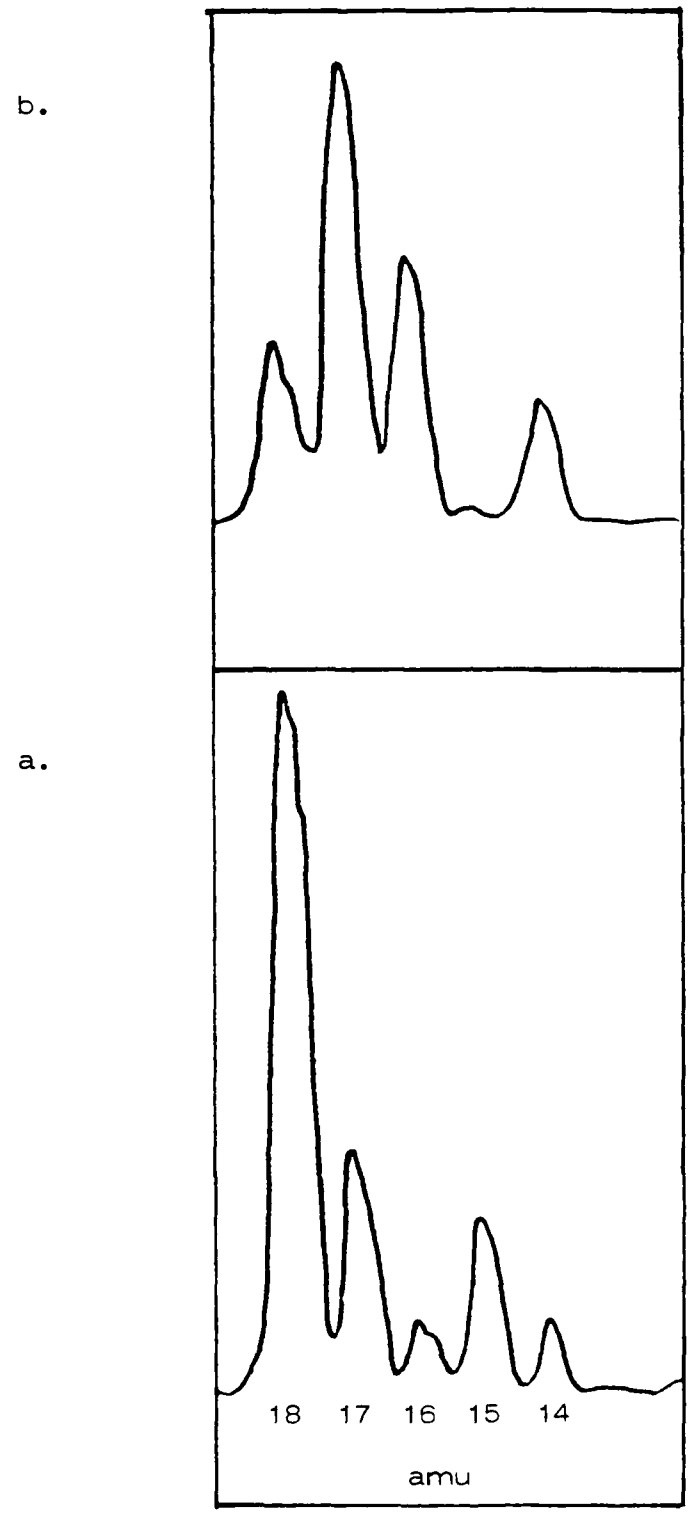


Fig. 12. High temperature thermal decomposition mass spectra of the copolymer 50/50 MNAMMO/AMMO (a) and the homopolymer AMMO (b) in the 14 - 18 amu range

and azido oxetane monomer (AZOX). Decomposition was initiated at approximately 120 C, with activation energies for the three materials approximately 170 kJ mol^{-1}. The primary mechanism for the decomposition is the release of molecular N_2. Secondary decomposition occurring at temperatures above 150 C included the fracturing of the three-carbon backbone of both the polymers and the monomer. Higher decomposition temperature species included HCN, HCO, and smaller amu fragments.

B. Annual Summary Report - September 1982

Thermal decomposition studies were conducted on AZOX and AMMO homopolymers and on 50-50% BAMO-AZOX and 50-50% BAMO-AMMO copolymers. Decomposition was initiated at approximately 120 C, with activation energies for the materials approximately 170 kJ mol^{-1}. The primary mechanism for the decomposition is the release of molecular N_2. Backbone decomposition occurs at temperatures above 150 C with thermal destruction of the three-carbon chain. A thermal decomposition study of a new copolymer consisting of an azido (BAMO) and nitrato ester, bis nitrato methyl oxetane (DNAO) showed both azide and nitrato group decomposition at differing rates. Preliminary mass spectrometric studies of the decomposition of a new amino nitro ring compound, $C_6H_8N_8O_{12}$, indicated NO_2 release with ring stability. Qualitative UV irradiation experiments at 2540 Å and 3660 Å wave lengths then were conducted on AZOX and AMMO homopolymers and 50-50% BAMO-AMMO and 50-50% BAMO-AZOX copolymers. Upwards of 25% of the polymeric N_2 was released with considerable cross-linking. The samples changed from viscous liquids to gummy, rubbery semi-solids. The irradiated samples were maintained for a number of weeks under ordinary atmospheric conditions as well as under vacuum without any indication of autocatalysis.

C. Annual Summary Report - September 1983

Thermal decomposition studies were performed on several azido and nitrato polymers and copolymers. Decomposition studies also included thermal plasticizers and novel nitramines. The 50-50% copolymer of BAMO-BNMO decomposes initially through the nitrato constituent at approximately 100 C followed by the azide decomposition. The thermal degradation mechanism for BEMO appears to be a stepwise breaking of the

ethoxy-methyl bonds followed by the stripping of the methylene groups. BFMO is stable to temperatures greater than 200 C with initial decomposition products of HF, with considerable depolymerization occurring. The major decomposition product of the NSWC novel nitramine, $C_6H_8N_8O_{12}$, is the eight-membered nitramine ring less two NO_2 molecules, molecular weight 292. The decomposition product is stable in the gas phase at 300 C.

D. Annual Summary Report - September 1984

Effusion mass spectrometric investigations were performed on a new nitramine, 1,3,3 trinitro azetidine; a nitramine monomer and homopolymer, 3-methyl nitramino methyl 3-methyl oxetane, MNAMMO; poly (3-nitratomethyl 3-methyl) oxetane, NMMO; a copolymer consisting of 30% wt% random copolymer of bis (methoxymethyl) oxetane and poly-tetrahydrofuran, BEMO/p-THF/BMMO; and a cellulose acetate butyrate, CAB. From the mass spectra decomposition mechanisms were proposed and activation energies calculated. The degradation of the copolymer BEMO/BMMO/p-THF shows the influence of the individual homopolymers in that the decomposition products are those of the three constituents.

REFERENCES

1. M. Farber, M. A. Frisch and H. C. Ko, Trans. Faraday Soc. 65, 3202 (1969).
2. M. Farber, S. P. Harris and R. D. Srivastava, Combustion and Flame 55, 203 (1984).
3. M. Farber and R. D. Srivastava, Chem. Phys. Lett. 80, 345 (1981).
4. M. Farber and R. D. Srivastava, Chem. Phys. Lett. 64, 307 (1979).
5. G. E. Manser, R. W. Fletcher, M. R. Knight, Final Report, Contract N00014-82-C-0800, Morton Thiokol, Inc. Project JM101, August 1985.
6. T. Brill, University of Delaware, private communication to G. E. Manser (see reference 5 above).

Ser 432/84/211 SYN
Revised January 1985

(SYN)

DISTRIBUTION LIST

Dr. R.S. Miller
Office of Naval Research
Code 432P
Arlington, VA 22217
(10 copies)

Dr. A.L. Slafkosky
Scientific Advisor
Commandant of the Marine Corps
Code RD-1
Washington, DC 20380

JHU Applied Physics Laboratory
ATTN: CPIA (Mr. T.W. Christian)
Johns Hopkins Rd.
Laurel, MD 20707

Dr. Kenneth D. Hartman
Hercules Aerospace Division
Hercules Incorporated
Alleghany Ballistic Lab
P.O. Box 210
Washington, DC 21502

Mr. Otto K. Heiney
AFATL-DLJG
Elgin AFB, FL 32542

Dr. Merrill K. King
Atlantic Research Corp.
5390 Cherokee Avenue
Alexandria, VA 22312

Dr. R.L. Lou
Aerojet Strategic Propulsion Co.
Bldg. 05025 - Dept 5400 - MS 167
P.O. Box 15699C
Sacramenta, CA 95813

Dr. R. Olsen
Aerojet Strategic Propulsion Co.
Bldg. 05025 - Dept 5400 - MS 167
P.O. Box 15699C
Sacramento, CA 95813

Dr. J. Pastine
Naval Sea Systems Command
Code 06R
Washington, DC 20362

Dr. Henry P. Marshall
Dept. 93-50, Bldg 204
Lockheed Missile & Space Co.
3251 Hanover St.
Palo Alto, CA 94304

Dr. Ingo W. May
Army Ballistic Research Lab.
ARRADCOM
Code DRXBR - 1BD
Aberdeen Proving Ground, MD 21005

Dr. R. McGuire
Lawrence Livermore Laboratory
University of California
Code L-324
Livermore, CA 94550

P.A. Miller
736 Leavenworth Street, #6
San Francisco, CA 94109

Dr. W. Moniz
Naval Research Lab.
Code 6120
Washington, DC 20375

Dr. K.F. Mueller
Naval Surface Weapons Center
Code R11
White Oak
Silver Spring, MD 20910

Prof. M. Nicol
Dept. of Chemistry & Biochemistry
University of California
Los Angeles, CA 90024

Ser 432/84/211 SYN
Revised January 1985

(SYN)

DISTRIBUTION LIST

Dr. Randy Peters
Aerojet Strategic Propulsion Co.
Bldg. 05025 - Dept 5400 - MS 167
P.O. Box 15699C
Sacramento, CA 95813

Dr. D. Mann
U.S. Army Research Office
Engineering Division
Box 12211
Research Triangle Park, NC 27709-2211

Mr. R. Geisler
ATTN: DY/MS-24
AFRPL
Edwards AFB, CA 93523

Naval Air Systems Command
ATTN: Mr. Bertram P. Sobers
NAVAIR-320G
Jefferson Plaza 1, RM 472
Washington, DC 20361

R.B. Steele
Aerojet Strategic Propulsion Co.
P.O. Box 15699C
Sacramento, CA 95813

Mr. M. Stosz
Naval Surface Weapons Center
Code R10B
White Oak
Silver Spring, MD 20910

Mr. E.S. Sutton
Thiokol Corporation
Elkton Division
P.O. Box 241
Elkton, MD 21921

Dr. Grant Thompson
Morton Thiokol, Inc.
Wasatch Division
MS 240 P.O. Box 524
Brigham City, UT 84302

Mr. L. Roslund
Naval Surface Weapons Center
Code R10C
White Oak, Silver Spring, MD 20910

Dr. David C. Sayles
Ballistic Missile Defense
Advanced Technology Center
P.O. Box 1500
Huntsville, AL 35807

Director
US Army Ballistic Research Lab.
ATTN: DRXBR-IBD
Aberdeen Proving Ground, MD 21005

Commander
US Army Missile Command
ATTN: DRSMI-RKL
Walter W. Wharton
Redstone Arsenal, AL 35898

T. Yee
Naval Weapons Center
Code 3265
China Lake, CA 93555

Dr. E. Zimet
Office of Naval Technology
Code 071
Arlington, VA 22217

Dr. Ronald L. Derr
Naval Weapons Center
Code 389
China Lake, CA 93555

T. Boggs
Naval Weapons Center
Code 389
China Lake, CA 93555

Lee C. Estabrook, P.E.
Morton Thiokol, Inc.
P.O. Box 30058
Shreveport, LA 71130

Ser 432/84/211 SYN
Revised January 1985

(SYN)

DISTRIBUTION LIST

Dr. R.F. Walker
Chief, Energetic Materials Division
DRSMC-LCE (D), B-3022
USA ARDC
Dover, NJ 07801

Dr. D.D. Dillehay
Morton Thiokol, Inc.
Longhorn Division
Marshall, TX 75670

Dr. Janet Wall
Code 012
Director, Research Administration
Naval Postgraduate School
Monterey, CA 93943

G.T. Bowman
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

R.E. Shenton
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Brian Wheatley
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Mike Barnes
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Mr. G. Edwards
Naval Sea Systems Command
Code 62R32
Washington, DC 20362

Dr. Lionel Dickinson
Naval Explosive Ordinance
Disposal Tech. Center
Code D
Indian Head, MD 20340

C. Dickinson
Naval Surface Weapons Center
White Oak, Code R-13
Silver Spring, MD 20910

Prof. J.T. Dickinson
Washington State University
Dept. of Physics 4
Pullman, WA 99164-2814

Prof. John Deutch
MIT
Department of Chemistry
Cambridge, MA 02139

M.H. Miles
Dept. of Physics
Washington State University
Pullman, WA 99164-2814

Dr. E.H. deButts
Hercules Aerospace Co.
P.O. Box 27408
Salt Lake City, UT 84127

Dr. T.F. Davidson
Vice President, Technical
Morton Thiokol, Inc.
Aerospace Group
110 North Wacker Drive
Chicago, IL 60606

David A. Flanigan
Director, Advanced Technology
Morton Thiokol, Inc.
Aerospace Group
110 North Wacker Drive
Chicago, IL 60606

Ser 432/84/211 SYN
Revised January 1985

(SYN)

DISTRIBUTION LIST

Mr. J. Consaga
Naval Surface Weapons Center
Code R-16
Indian Head, MD 20640

Naval Sea Systems Command
ATTN: Mr. Charles M. Christensen
NAVSEA62R2
Crystal Plaza, Bldg. 6, Rm 806
Washington, DC 20362

Mr. R. Beauregard
Naval Sea Systems Command
SEA 64E
Washington, DC 20362

Dr. Anthony J. Matuszko
Air Force Office of Scientific Research
Directorate of Chemical & Atmospheric Sciences
Bolling Air Force Base
Washington, DC 20332

Dr. Michael Chaykovsky
Naval Surface Weapons Center
Code R11
White Oak
Silver Spring, MD 20910

J.J. Rocchio
USA Ballistic Research Lab.
Aberdeen Proving Ground, MD 21005-5066

G.A. Zimmerman
Aerojet Tactical Systems
P.O. Box 13400
Sacramento, CA 95813

B. Swanson
INC-4 MS C-346
Los Alamos National Laboratory
Los Alamos, NM 87545

Dr. L.H. Caveny
Air Force Office of Scientific Research
Directorate of Aerospace Sciences
Bolling Air Force Base
Washington, DC 20332

W.G. Roger
Code 5253
Naval Ordance Station
Indian Head, MD 20640

Dr. Donald L. Bell
Air Force Office of Scientific Research
Directorate of Chemical & Atmospheric Sciences
Bolling Air Force Base
Washington, DC 20332

Dr. H.G. Adolph
Naval Surface Weapons Center
Code R11
White Oak
Silver Spring, MD 20910

U.S. Army Research Office
Chemical & Biological Sciences Division
P.O. Box 12211
Research Triangle Park, NC 27709

G. Butcher
Hercules, Inc.
MS X2H
P.O. Box 98
Magna, Utah 84044

W. Waesche
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Ser 432/84/211 SYN
Revised January 1985

(SYN)

DISTRIBUTION LIST

Dr. James T. Bryant
Naval Weapons Center
Code 3205B
China Lake, CA 93555

Dr. L. Rothstein
Assistant Director
Naval Explosives Dev. Engineering Dept.
Naval Weapons Station
Yorktown, VA 23691

Dr. M.J. Kamlet
Naval Surface Weapons Center
Code R11
White Oak, Silver Spring, MD 20910

Dr. Henry Webster, III
Manager, Chemical Sciences Branch
ATTN: Code 5063
Crane, IN 47522

Dr. R.S. Valentini
United Technologies Chemical Systems
P.O. Box 50015
San Jose, CA 95150-0015

Administrative Contracting
Officer (see contract for
address)
(1 copy)

Defense Technical Information Center
Bldg. 5, Cameron Station
Alexandria, VA 22314
(12 copies)

Arpad Junasz
Code DRDAR-IBD
Ballistic Research Lab
Aberdeen, MD 21005

Mr. C. Gotzmer
Naval Surface Weapons Center
Code R-11
White Oak
Silver Spring, MD 20910

Dr. John S. Wilkes, Jr.
FJSRL/NC
USAF Academy, CO 80840

Dr. H. Rosenwasser
Naval Air Systems Command
AIR-320R
Washington, DC 20361

Dr. A. Nielsen
Naval Weapons Center
Code 385
China Lake, CA 93555

Dr. Joyce J. Kaufman
The Johns Hopkins University
Department of Chemistry
Baltimore, MD 21218

Dr. J.R. West
Morton Thiokol, Inc.
P.O. Box 30058
Shreveport, LA 71130

Director
Naval Research Laboratory
Attn: Code 2627
Washington, DC 20375
(6 copies)

Dr. Robert J. Schmitt
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Dr. Michael D. Coburn
Los Alamos National Lab
M-1, Explosives Technology
Mail Stop, C920
Los Alamos, NM 87545

Ser 432/84/212
Revised January 1985

(SYN)

DISTRIBUTION LIST

Dr. G. Neece
Office of Naval Research
Code 413
Arlington, VA 22217

Mr. C.M. Havlik
0/83-10, B/157-3W
Lockheed Missiles & Space Co., Inc.
P.O. Box 504
Sunnvale, CA 94086

Dr. Philip Howe
Ballistic Research Labatory
Code DRXBR-TBD
Aberdeen Proving Ground, MD 21005

Prof. C. Sue Kim
Department of Chemistry
California State University, Sacramento
Sacramento, California 95819

Mr. J. Moniz
Naval Ordnance Station
Code 5253L
Indian Head, MD 20640

Dr. R. Reed Jr.
Naval Weapons Center
Code 38904
China Lake, CA 93555

L.H. Sperling
Materials Research Center #32
Lehigh University
Bethlehem, PA 18015

Dr. Kurt Baum
Fluorochem, Inc.
680 South Ayon Ave.
Azusa, CA 91702

Dr. Andrew C. Victor
Naval Weapons Center
Code 3208
China Lake, CA 93555

Dr. J.C. Hinshaw
Morton Thiokol Inc.
P.O. Box 524
Mail Stop 240
Brigham City, Utah 84302

Dr. V.J. Keenan
Anal-Syn Lab. Inc.
P.O. Box 547
Paoli, PA 19301

G.E Manser
Morton Thiokol
Wasatch Division
P.O. Box 524
Brigham City, Utah 84302

P. Politzer
Chemistry Department
University of New Orleans
New Orleans, Louisiana 70148

Mr. David Siegel
Office of Naval Research
Code 253
Arlington, VA 22217

Dr. Rodney L. Willer
Morton Thiokol, Inc.
P.O. Box 241
Elkton, MD 21921

Dr. R. Atkins
Naval Weapons Center
Code 3852
China Lake, CA 93555

Ser 432/84/212
Revised January 1985

(SYT)

DISTRIBUTION LIST

Prof. J.H. Boyer
University of Illinois
Department of Chemistry
Box 4348
Chicago, Illinois 60680

Prof. J.C. Chien
University of Massachusetts
Department of Chemistry
Amherst, MA 03003

Dr. B. David Halpern
Polysciences, Inc.
Paul Valley Industrial Park
Warrington, PA 18976

Dr. M.B. Frankel
Rockwell International
Rocketdyne Division
6633 Canoga Avenue
Canoga Park, CA 91304

Dr. R.A. Earl
Hercules, Inc.
Magna, Utah 84109

Dr. C. Bedford
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Dr. Robert R. Ryan
INC-4, MS C346
Los ALamos National Laboratory
Los Alamos, New Mexico 87545

Dr. Robert D. Champman
AFRPL/LKLR
Edwards AFB, CA 93525

Dr. L. Erwin
MIT
Room 35-008
Cambridge, MA 02139

Dr. M. Farber
Space Sciences, Inc.
135 W. Maple Avenue
Monrovia, CA 91016

Dr. W.H. Graham
Morton Thiokol, Inc.
Hunstville Division
Hunstville, AL 35807-7501

Dr. C. Coon
Lawrence Livermore Lab.
University of California
P.O. Box 808
Livermore, CA 94550

Dr. R. Gilardi
Naval Research Laboratory
Code 6030
Washington, DC 20375

Dr. Alan Marchand
Dept. of Chemistry
North Texas State University
NTSU Station, Box 5068
Denton, Texas 76203

T.B. Brill
Department of Chemistry
University of Delaware
Newark, Delaware 19716

Dr. A.A. Defusco
Code 3858
Naval Weapons Center
China Lake, CA 93555

Dr. Richard A. Hollins
Naval Weapons Center
Code 3853
China Lake, CA 93555

Dr. R. Armstrong
MIT
Room 66-505
Cambridge, MA 02139

Professor Philip E. Eaton
Department of Chemistry
University of Chicago
5735 South Ellis Avenue
Chicago, IL 60637

Ser 432/84/211DYN
Revised January 1985

(DYN)

DISTRIBUTION LIST

R.E. Shenton
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Brian Wheatley
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Mike Barnes
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Mr. G. Edwards
Naval Sea Systems Command
Code 62R32
Washington, DC 20362

Dr. Lionel Dickinson
Naval Explosive Ordinance
Disposal Tech. Center
Code D
Indian Head, MD 20340

C. Dickinson
Naval Surface Weapons Center
White Oak, Code R-13
Silver Spring, MD 20910

Prof. J.T. Dickinson
Washington State University
Dept. of Physics 4
Pullman, WA 99164-2814

Prof. John Deutch
MIT
Department of Chemistry
Cambridge, MA 02139

M.H. Miles
Dept. of Physics
Washington State University
Pullman, WA 99164-2814

Dr. E.H. deButts
Hercules Aerospace Co.
P.O. Box 27408
Salt Lake City, UT 84127

Dr. T.F. Davidson
Vice President, Technical
Morton Thiokol, Inc.
Aerospace Group
110 North Wacker Drive
Chicago, Illinois 60606

David A. Flanigan
Director, Advanced Technology
Morton Thiokol, Inc.
Aerospace Group
110 North Wacker Drive
Chicago, Illinois 60606

Mr. J. Consaga
Naval Surface Weapons Center
Code R-16
Indian Head, MD 20640

Dr. L.H. Caveny
Air Force Office of Scientific
Research
Directorate of Aerospace Sciences
Bolling Air Force Base
Washington, DC 20332

Naval Sea Systems Command
ATTN: Mr. Charles M. Christensen
NAVSEA-62R2
Crystal Plaza, Bldg. 6, Rm 806
Washington, DC 20362

W.G. Roger
Code 5253
Naval Ordance Station
Indian Head, MD 20640

Mr. R. Beauregard
Naval Sea Systems Command
SEA 64E
Washington, DC 20362

Dr. Donald L. Ball
Air Force Office of Scientific
Research
Directorate of Chemical &
Atmospheric Sciences
Bolling Air Force Base
Washington, DC 20332

Ser 432/84/211DYN
Revised January 1985

(DYN)

DISTRIBUTION LIST

Dr. R.S. Miller
Office of Naval Research
Code 432P
Arlington, VA 22217
(10 copies)

Dr. J. Pastine
Naval Sea Systems Command
Code 06R
Washington, DC 20362

Dr. Kenneth D. Hartman
Hercules Aerospace Division
Hercules Incorporated
Alleghany Ballistic Lab
P.O. Box 210
Washington, DC 21502

Mr. Otto K. Heiney
AFATL-DLJG
Elgin AFB, FL 32542

Dr. Merrill K. King
Atlantic Research Corp.
5390 Cherokee Avenue
Alexandria, VA 22312

Dr. R.L. Lou
Aerojet Strategic Propulsion Co.
Bldg. 05025 - Dept 5400 - MS 167
P.O. Box 15699C
Sacramenta, CA 95813

Dr. R. Olsen
Aerojet Strategic Propulsion Co.
Bldg. 05025 - Dept 5400 - MS 167
P.O. Box 15699C
Sacramento, CA 95813

Dr. Randy Peters
Aerojet Strategic Propulsion Co.
Bldg. 05025 - Dept 5400 - MS 167
P.O. Box 15699C
Sacramento, CA 95813

Dr. D. Mann
U.S. Army Research Office
Engineering Division
Box 12211
Research Triangle Park, NC 27709-2211

Dr. L.V. Schmidt
Office of Naval Technology
Code 07CT
Arlington, VA 22217

JHU Applied Physics Laboratory
ATTN: CPIA (Mr. T.W. Christian)
Johns Hopkins Rd.
Laurel, MD 20707

Dr. R. McGuire
Lawrence Livermore Laboratory
University of California
Code L-324
Livermore, CA 94550

P.A. Miller
736 Leavenworth Street, #6
San Francisco, CA 94109

Dr. W. Moniz
Naval Research Lab.
Code 6120
Washington, DC 20375

Dr. K.F. Mueller
Naval Surface Weapons Center
Code R11
White Oak
Silver Spring, MD 20910

Prof. M. Nicol
Dept. of Chemistry & Biochemistry
University of California
Los Angeles, CA 90024

Mr. L. Roslund
Naval Surface Weapons Center
Code R10C
White Oak, Silver Spring, MD 20910

Dr. David C. Sayles
Ballistic Missile Defense
Advanced Technology Center
P.O. Box 1500
Huntsville, AL 35807

Ser 432/84/211DYN
Revised January 1985

(DYN)

DISTRIBUTION LIST

Mr. R. Geisler
ATTN: DY/MS-24
AFRPL
Edwards AFB, CA 93523

Naval Air Systems Command
ATTN: Mr. Bertram P. Sobers
NAVAIR-320G
Jefferson Plaza 1, RM 472
Washington, DC 20361

R.B. Steele
Aerojet Strategic Propulsion Co.
P.O. Box 15699C
Sacramento, CA 95813

Mr. M. Stosz
Naval Surface Weapons Center
Code R10B
White Oak
Silver Spring, MD 20910

Mr. E.S. Sutton
Thiokol Corporation
Elkton Division
P.O. Box 241
Elkton, MD 21921

Dr. Grant Thompson
Morton Thiokol, Inc.
Wasatch Division
MS 240 P.O. Box 524
Brigham City, UT 84302

Dr. R.S. Valentini
United Technologies Chemical Systems
P.O. Box 50015
San Jose, CA 95150-0015

Dr. R.F. Walker
Chief, Energetic Materials Division
DRSMC-LCE (D), B-3022
USA ARDC
Dover, NJ 07801

Dr. Janet Wall
Code 012
Director, Research Administration
Naval Postgraduate School
Monterey, CA 93943

Director
US Army Ballistic Research Lab.
ATTN: DRXBR-IBD
Aberdeen Proving Ground, MD 21005

Commander
US Army Missile Command
ATTN: DRSMI-RKL
Walter W. Wharton
Redstone Arsenal, AL 35898

Dr. Ingo W. May
Army Ballistic Research Lab.
ARRADCOM
Code DRXBR - IBD
Aberdeen Proving Ground, MD 21005

Dr. E. Zimet
Office of Naval Technology
Code 071
Arlington, VA 22217

Dr. Ronald L. Derr
Naval Weapons Center
Code 389
China Lake, CA 93555

T. Boggs
Naval Weapons Center
Code 389
China Lake, CA 93555

Lee C. Estabrook, P.E.
Morton Thiokol, Inc.
P.O. Box 30058
Shreveport, Louisiana 71130

Dr. J.R. West
Morton Thiokol, Inc.
P.O. Box 30058
Shreveport, Louisiana 71130

Dr. D.D. Dillehay
Morton Thiokol, Inc.
Longhorn Division
Marshall, TX 75670

G.T. Bowman
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Ser 432/84/211DYN
Revised January 1985

(DYN)

DISTRIBUTION LIST

Dr. Anthony J. Matuszko
Air Force Office of Scientific Research
Directorate of Chemical & Atmospheric Sciences
Bolling Air Force Base
Washington, DC 20332

Dr. Michael Chaykovsky
Naval Surface Weapons Center
Code R11
White Oak
Silver Spring, MD 20910

J.J. Rocchio
USA Ballistic Research Lab.
Aberdeen Proving Ground, MD 21005-5066

G.A. Zimmerman
Aerojet Tactical Systems
P.O. Box 13400
Sacramento, CA 95813

B. Swanson
INC-4 MS C-346
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Dr. James T. Bryant
Naval Weapons Center
Code 3205B
China Lake, CA 93555

Dr. L. Rothstein
Assistant Director
Naval Explosives Dev. Engineering Dept.
Naval Weapons Station
Yorktown, VA 23691

Dr. M.J. Kamlet
Naval Surface Weapons Center
Code R11
White Oak, Silver Spring, MD 20910

Dr. Henry Webster, III
Manager, Chemical Sciences Branch
ATTN: Code 5063
Crane, IN 47522

Dr. A.L. Slafkosky
Scientific Advisor
Commandant of the Marine Corps
Code RD-1
Washington, DC 20380

Dr. H.G. Adolph
Naval Surface Weapons Center
Code R11
White Oak
Silver Spring, MD 20910

U.S. Army Research Office
Chemical & Biological Sciences Division
P.O. Box 12211
Research Triangle Park, NC 27709

G. Butcher
Hercules, Inc.
MS X2H
P.O. Box 98
Magna, Utah 84044

W. Waesche
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Dr. John S. Wilkes, Jr.
FJSRL/NC
USAF Academy, CO 80840

Dr. H. Rosenwasser
AIR-320R
Naval Air Systems Command
Washington, DC 20361

Dr. Joyce J. Kaufman
The Johns Hopkins University
Department of Chemistry
Baltimore, MD 21218

Dr. A. Nielsen
Naval Weapons Center
Code 385
China Lake, CA 93555

Ser 432/84/340
Revised January 1985

(DYN)

DISTRIBUTION LIST

K.D. Pae
High Pressure Materials Research Lab.
Rutgers University
P.O. Box 909
Piscataway, NJ 08854

Dr. John K. Dienes
T-3, B216
Los Alamos National Lab.
P.O. Box 1663
Los Alamos, NM 87544

A.N. Gent
Institute Polymer Science
University of Akron
Akron, OH 44325

Dr. D.A. Shockey
SRI International
333 Ravenswood Ave.
Menlo Park, CA 94025

Dr. R.B. Kruse
Morton Thiokol, Inc.
Huntsville Division
Huntsville, AL 35807-7501

G. Butcher
Hercules, Inc.
P.O. Box 98
Magna, UT 84044

W. Waesche
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Dr. R. Bernecker
Naval Surface Weapons Center
Code R13
White Oak
Silver Spring, MD 20910

Prof. Edward Price
Georgia Institute of Tech.
School of Aerospace Engineering
Atlanta, GA 30332

J.A. Birkett
Naval Ordnance Station
Code 5253K
Indian Head, MD 20640

Prof. R.W. Armstrong
University of Maryland
Dept. of Mechanical Engineering
College Park, MD 20742

Herb Richter
Code 385
Naval Weapons Center
China Lake, CA 93555

J.T. Rosenberg
SRI International
333 Ravenswood Ave.
Menlo Park, CA 94025

G.A. Zimmerman
Aeroject Tactical Systems
P.O. Box 13400
Sacramento, CA 95813

Prof. Kenneth Kuo
Pennsylvania State University
Dept. of Mechanical Engineering
University Park, PA 16802

T.L. Boggs
Naval Weapons Center
Code 3891
China Lake, CA 93555

Ser 432/84/340
Revised January 1985

(DYN)

DISTRIBUTION LIST

Dr. C.S. Coffey
Naval Surface Weapons Center
Code R13
White Oak
Silver Spring, MD 20910

D. Curran
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

E.L. Throckmorton
Code SP-2731
Strategic Systems Program Office
Crystal Mall #3, RM 1048
Washington, DC 23076

Dr. R. Martinson
Lockheed Missiles and Space Co.
Research and Development
3251 Hanover Street
Palo Alto, CA 94304

C. Gotzmer
Naval Surface Weapons Center
Code R-11
White Oak
Silver Spring, MD 20910

G.A. Lo
3251 Hanover Street
B204 Lockheed Palo Alto Research Lab
Palto Alto, CA 94304

R.A. Schapery
Civil Engineering Department
Texas A&M University
College Station, TX 77843

J.M. Culver
Strategic Systems Projects Office
SSPO/SP-2731
Crystal Mall #3, RM 1048
Washington, DC 20376

Prof. G.D. Duvall
Washington State University
Department of Physics
Pullman, WA 99163

Dr. E. Martin
Naval Weapons Center
Code 3858
China Lake, CA 93555

Dr. M. Farber
135 W. Maple Avenue
Monnovia, CA 91016

W.L. Elban
Naval Surface Weapons Center
White Oak, Bldg. 343
Silver Spring, MD 20910

G.E. Manser
Morton Thiokol
Wasatch Division
P.O. Box 524
Brigham City, UT 84302

R.G. Rosemeier
Brimrose Corporation
7720 Belair Road
Baltimore, MD 20742

Ser 432/84/340
Revised January 1985

Administrative Contracting
Officer (see contract for
address)
(1 copy)

Director
Naval Research Laboratory
Attn: Code 2627
Washington, DC 20375
(6 copies)

Defense Technical Information Center
Bldg. 5, Cameron Station
Alexandria, VA 22314
(12 copies)

Dr. Robert Polvani
National Bureau of Standards
Metallurgy Division
Washington, D.C. 20234

Dr. Y. Gupta
Washington State University
Department of Physics
Pullman, WA 99163

END

DTIC

7-86